CMPG-767 Image Processing and Analysis

FUNDAMENTALS OF IMAGING

Some features of vision

- The innermost membrane of the eye is the retina

- Pattern vision is afforded by the distribution of discrete light receptors over the surface of the retina

- There are two classes of receptors: cones and rods

Some Features of Vision

- Cones (there are about 6-7 million cones in each eye) are highly sensitive to color. Each cone is connected to its own nerve end.
- Rods (there are about 75-150 million rods in each eye) are responsible for creation of a general, overall picture of the field of view. Rods are not sensitive to color and several of them are connected to a single nerve end.

Image Formation in the Eye

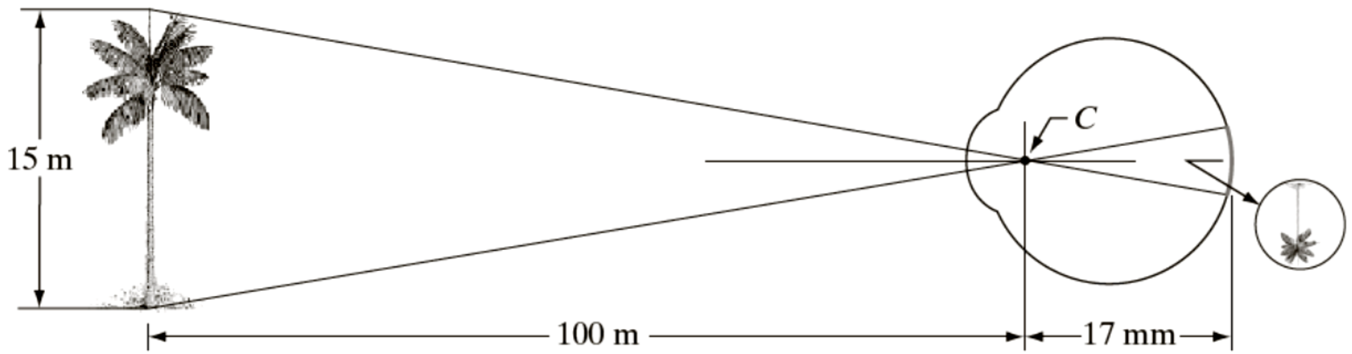


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point C is the optical center of the lens.

$$\frac{15}{100} = \frac{h}{17} \Rightarrow h = \frac{17 \times 15}{100}$$

h= height of the image created in the eye

Brightness Adaptation and Discrimination

- The range of light intensity levels to which the human visual system can adapt is on the order of 10^{10}

- However, our visual system is unable to percept so many intensity levels at a time. It can adapt itself to a small sub-range, which is determined by a logarithmic function of the light intensity

Brightness Adaptation and Discrimination

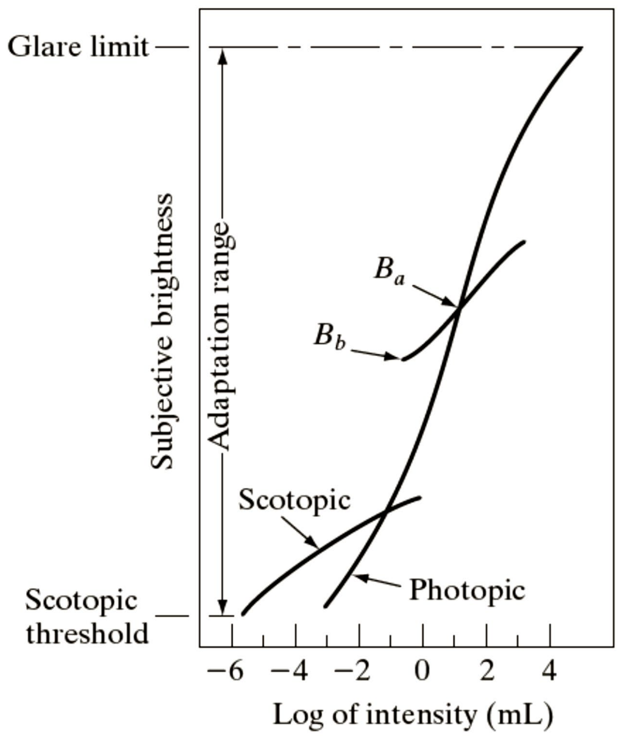
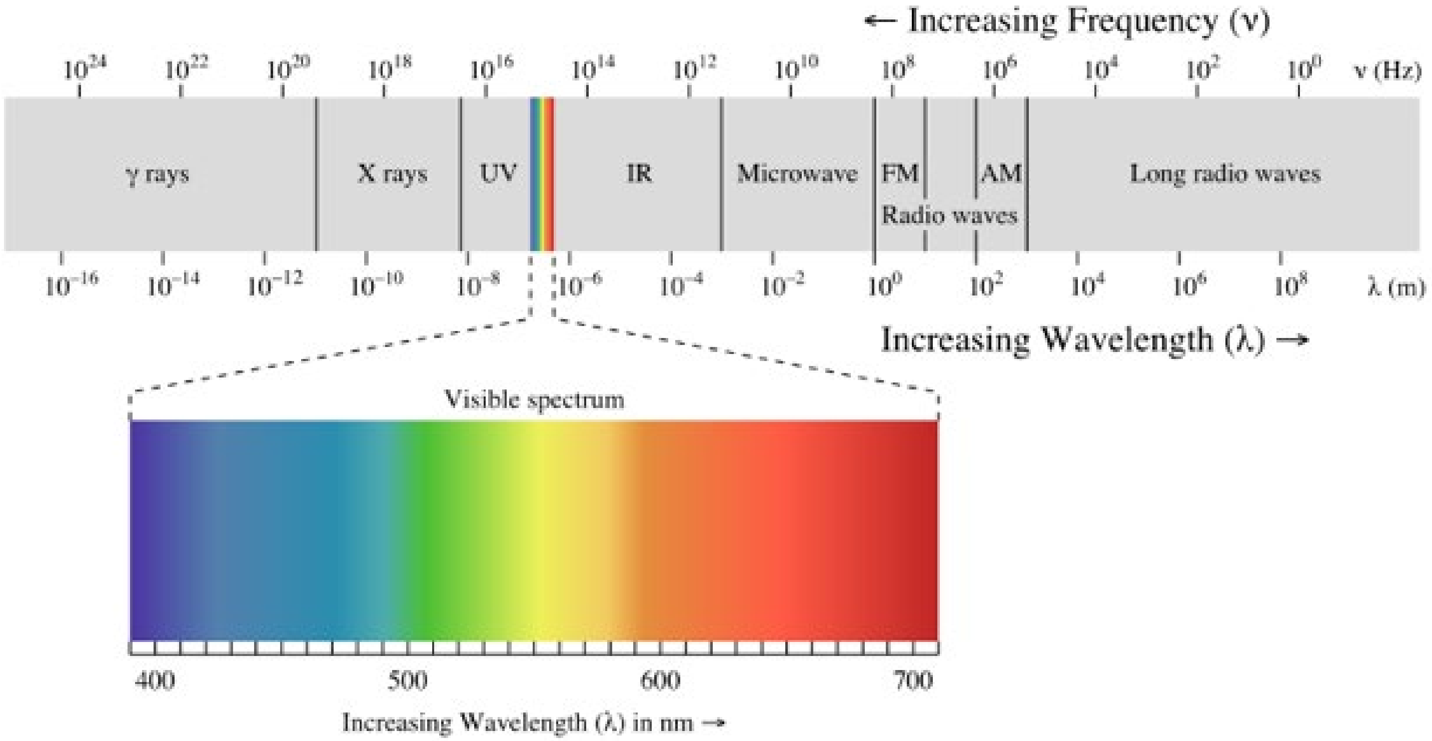


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

- Short cur intensity to which human visual system has adapted

Light and Electromagnetic Spectrum



$$\lambda = \frac{c}{v}$$ Correspondence between the wavelength and the frequency

$$E = hv$$ The Energy of the component of electromagnetic spectrum

c is the speed of light; *h* is Planck's constant

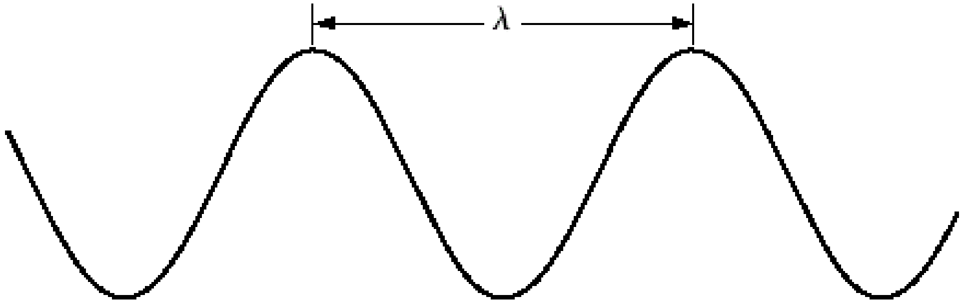
Light and Electromagnetic Spectrum

- Since energy is proportional to frequency, then the higher frequency is, the more energy is carried by the corresponding electromagnetic phenomenon – the more energy is per photon there

$$E = hv$$

Electromagnetic Wave and Wavelength

FIGURE 2.11 Graphical representation of one wavelength.



- The wavelength of an electromagnetic wave required to “see” an object, must be of the same size or smaller than the object
- For example, to see a water molecule (diameter 10^{-10} m), we would need a source capable of emitting in the far ultraviolet or soft X-ray region)

Monochromatic Light

- Light is a particular type of electromagnetic radiation (phenomenon) that can be sensed by the human eye.
- Monochromatic light is void of color. Its intensity varies from black to white.
- The levels of intensity of monochromatic light are called gray levels.
- The range of measured values of monochromatic light from black to white are called gray-scale.
- Monochromatic images are referred to as gray-scale images.

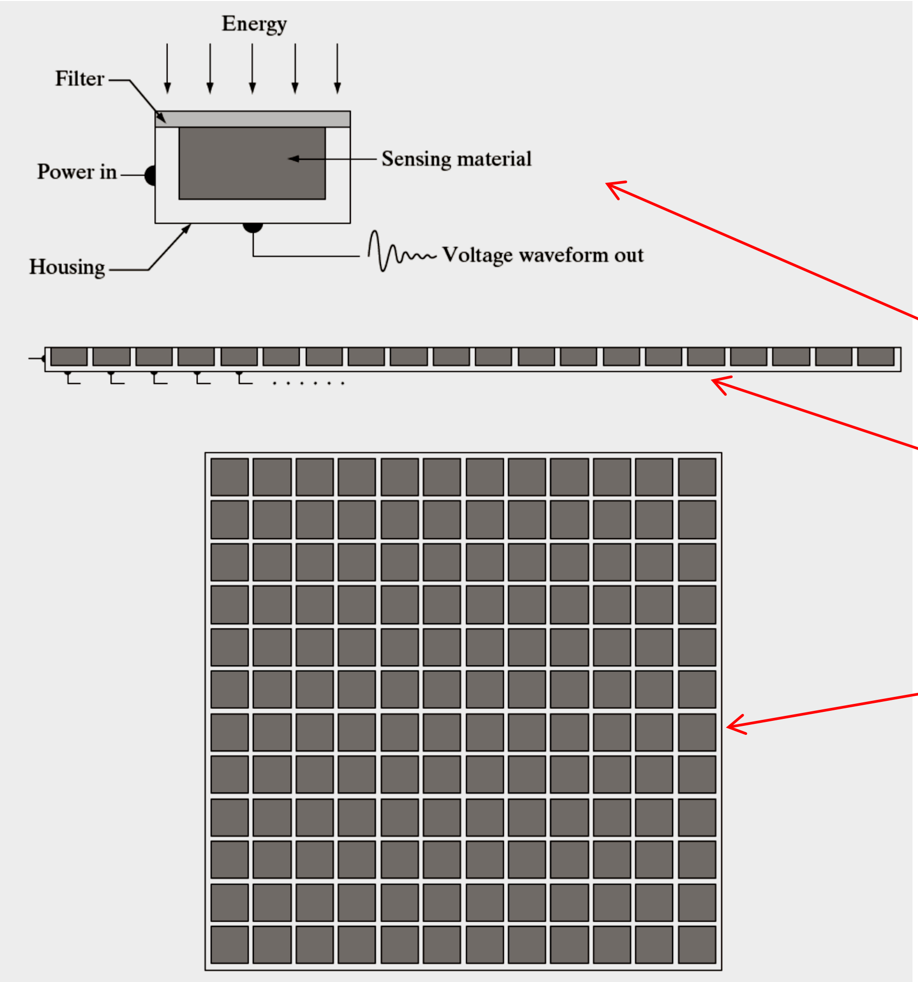
Light Properties

- Radiance (watts – W) is the total amount of energy that flows from the light source
- Luminance (lumens-lm) is a measure of the amount of energy an observer perceives from a light source (for example, in the infrared region it tends to zero, although the same light may have significant radiance)
- Brightness is a subjective descriptor of light perception (it is impossible to measure it)

Image Sensing and Acquisition

- Most of digital images are generated by the combination of an "illumination" (energy) source and the reflection or absorption of energy from that source by the elements of the "scene" being imaged.

Image Sensing and Acquisition



a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

Single Sensor

Line Sensor

Array Sensor – CCD
(a Charge-Coupled
Device)

Image Sensing and Acquisition

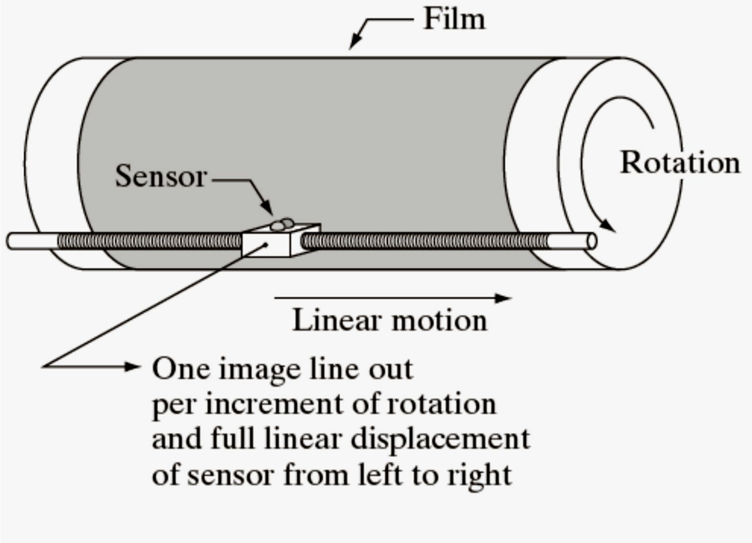


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

A single sensor

Image Sensing and Acquisition

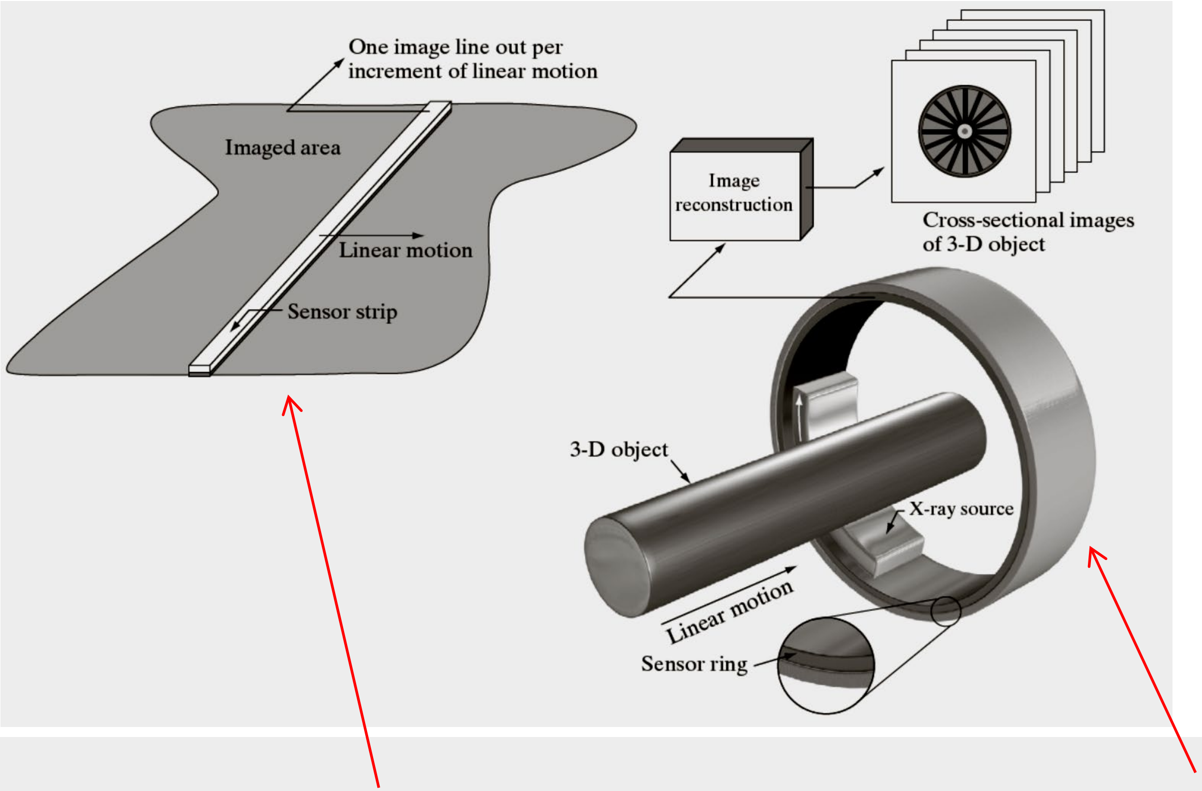


FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

Image Formation Model

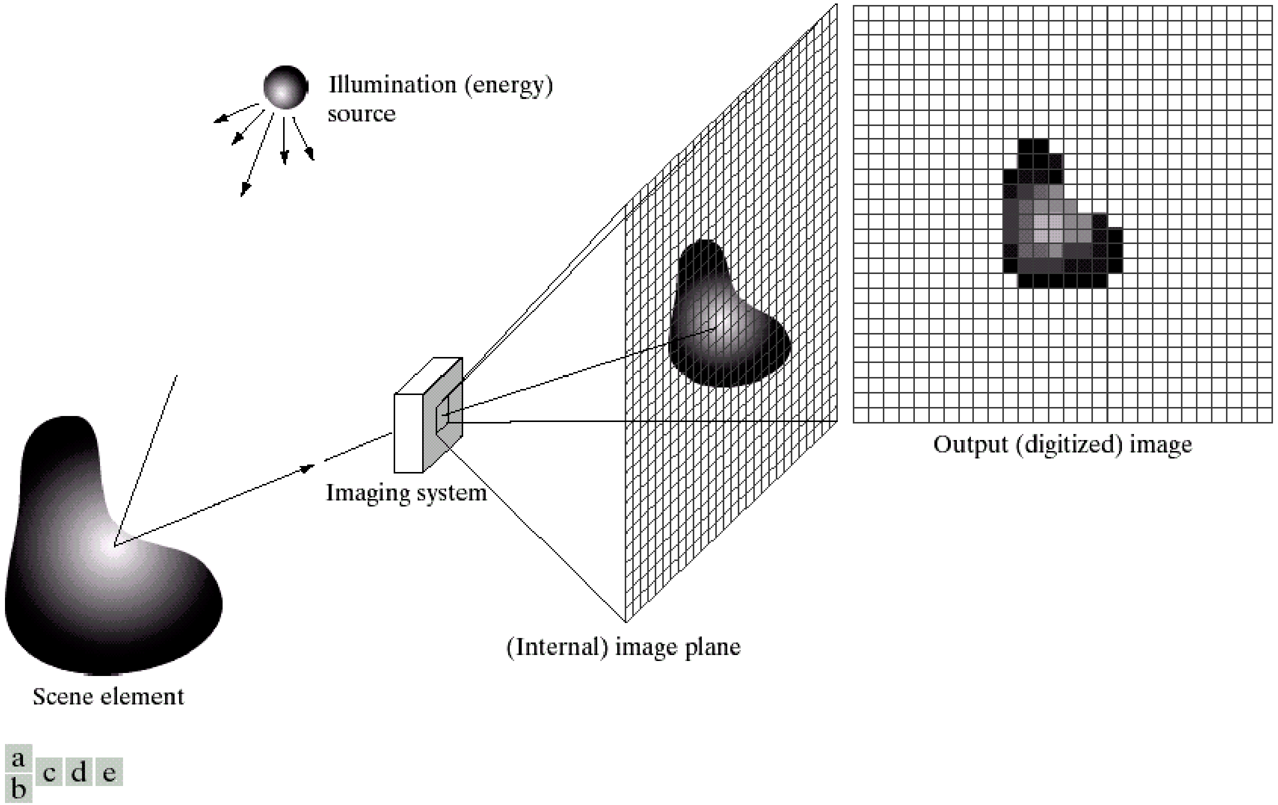


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Digital Image

- Mathematically, a digital image can be considered as a discrete function

$$f(x,y): D^2 \to I; D = \{0,1,2,\ldots,N-1\}, I = \{0,1,\ldots,k-1\}$$

- D^2 is a finite domain (which is called a spatial domain) of the image-function, and I is a co-domain of intensities of the image-function

Image Formation Model

- When an image $f(x, y)$ (*x* and *y* are spatial domain coordinates) is generated from a physical process, its intensity values are proportional to energy radiated by a physical source (by electromagnetic waves).
- $f(x, y)$ must be nonzero and finite:

$$0 < f(x, y) < \infty$$

Image Formation Model

- $f(x,y)$ is characterized by
- (1) the amount of source illumination $i(x,y)$ incident on the scene being viewed (illumination)
- (2) the amount of illumination reflected by (transmitted through for X-ray or γ-ray) the objects in this scene (reflectance) $r(x,y)$

$$f(x,y) = i(x,y)\,r(x,y)$$

$$0 < i(x,y) < \infty$$

$$0 < r(x,y) < 1$$

Image Formation Model

$$f(x,y) = i(x,y)\,r(x,y)$$

$$0 < i(x,y) < \infty$$

$$0 < r(x,y) < 1$$

- $i(x,y)$ is determined by illumination source
- $r(x,y)$ is determined by characteristics of the imaged objects
- $r(x,y) \to 0$ means total absorption
- $r(x,y) \to 1$ means total reflectance (passing through for X-ray or γ-ray)

Image Formation Model

- In any specific case, there are $L_{\min}$ and $L_{\max}$ that limit a range for $f(x, y)$
- If $l = f(x_0, y_0)$ then always $L_{\min} \le l \le L_{\max}$
- In practice, $L_{\min} = i_{\min} r_{\min} ; L_{\max} = i_{\max} r_{\max}$

- The interval $[L_{\min}, L_{\max}]$ is called the gray scale

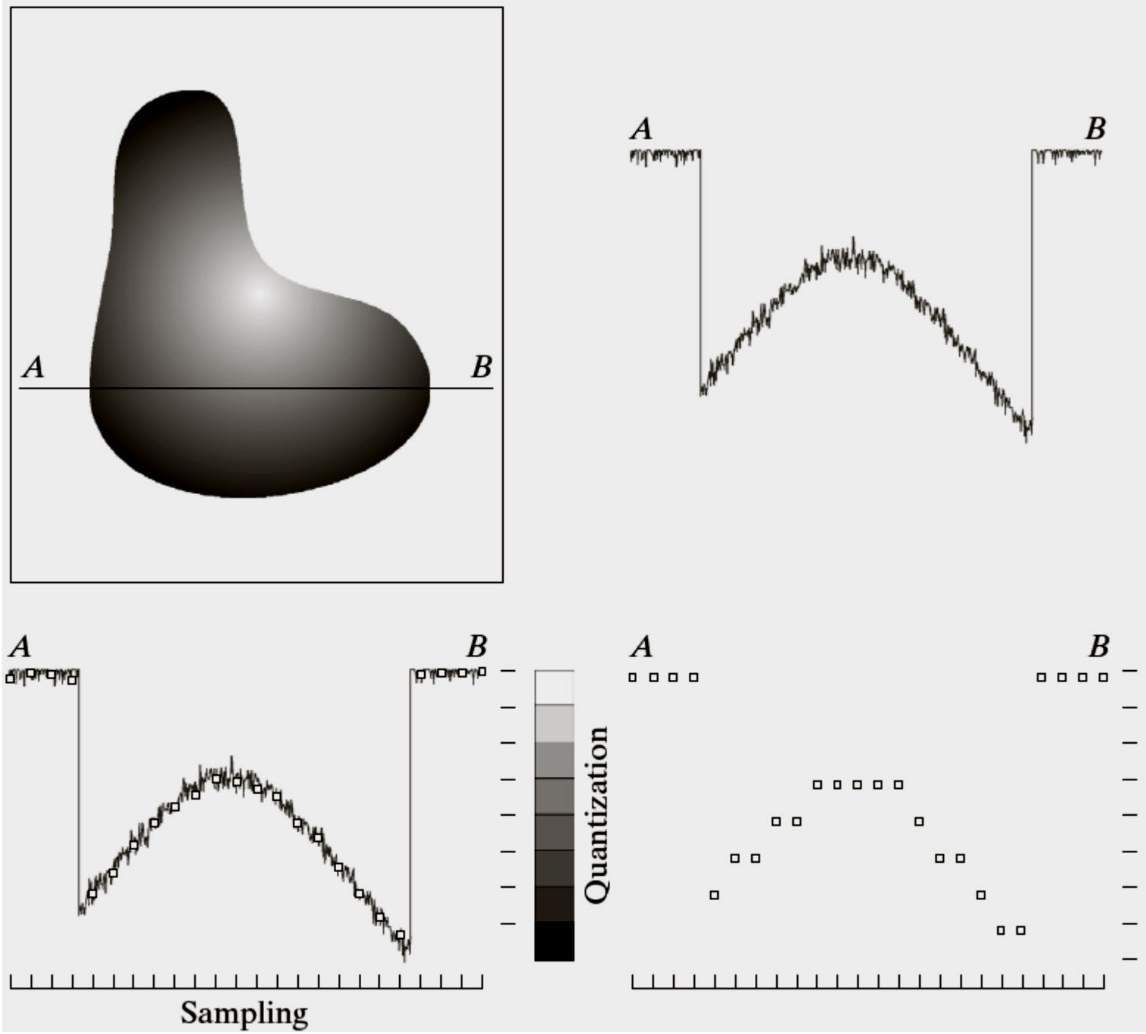
Concepts of Sampling and Quantization

- Any natural image is continuous with respect to the x- and y-coordinates, and in its amplitude

- Digitizing the coordinate values is called sampling

- Digitizing the intensity values is called quantization

Concepts of Sampling and Quantization



a b
c d

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Concepts of Sampling and Quantization

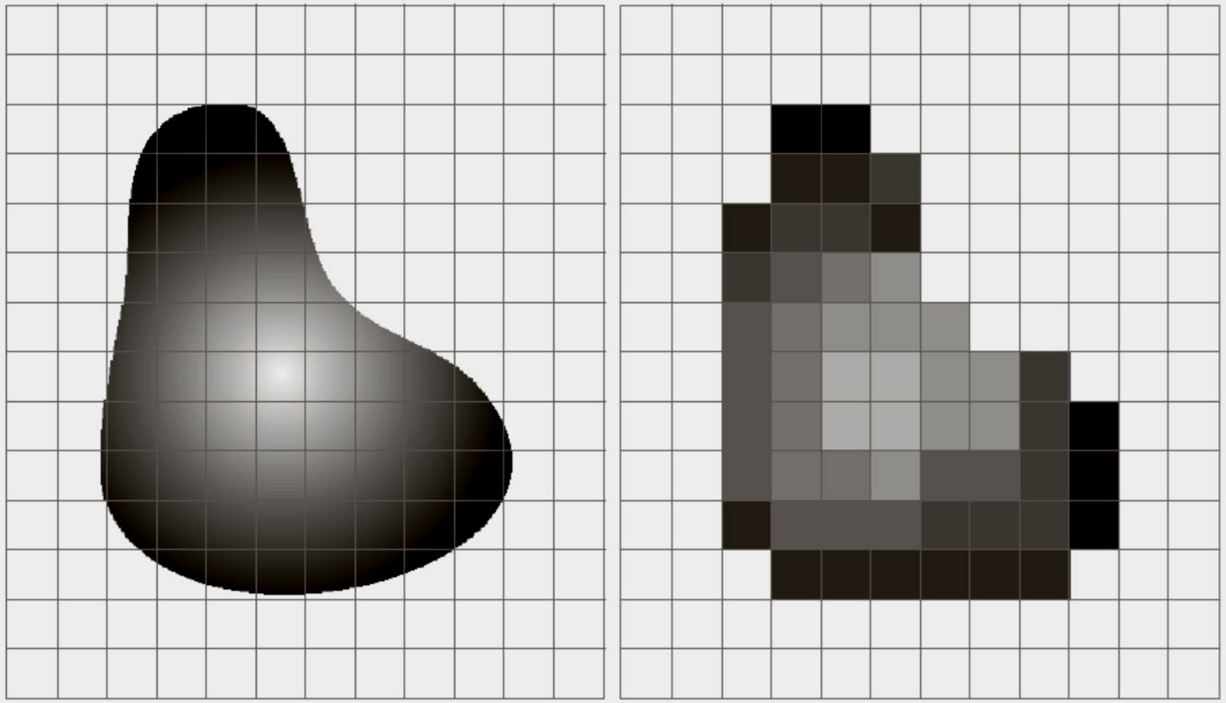


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Sampling Theorem

- Sampling theorem by Nyquist–Shannon–Kotelnikov-Whittaker (1949) establishes necessary condition for the ability to reconstruct a signal from its samples.
- Sampling theorem (1-D case, time domain).
  A bandlimited analog signal, which has been sampled, can be perfectly reconstructed from an infinite sequence of samples if the sampling rate exceeds $2N$ samples per second, where N is the highest frequency in the original signal. If a signal contains a component at exactly frequency N , then samples spaced at exactly $1/(2N)$ seconds do not completely determine the signal.

Sampling Theorem

- The signal x(t) is said to be bandlimited if for its Fourier transform

$$F_x(\omega) = \int_{-\infty}^{\infty} x(t) e^{-i2\pi\omega t} dt$$

if the following property holds:

$$F_x\left(\omega\right) = 0 \quad \text{for} \quad |\,\omega\,| > N$$

Sampling Theorem

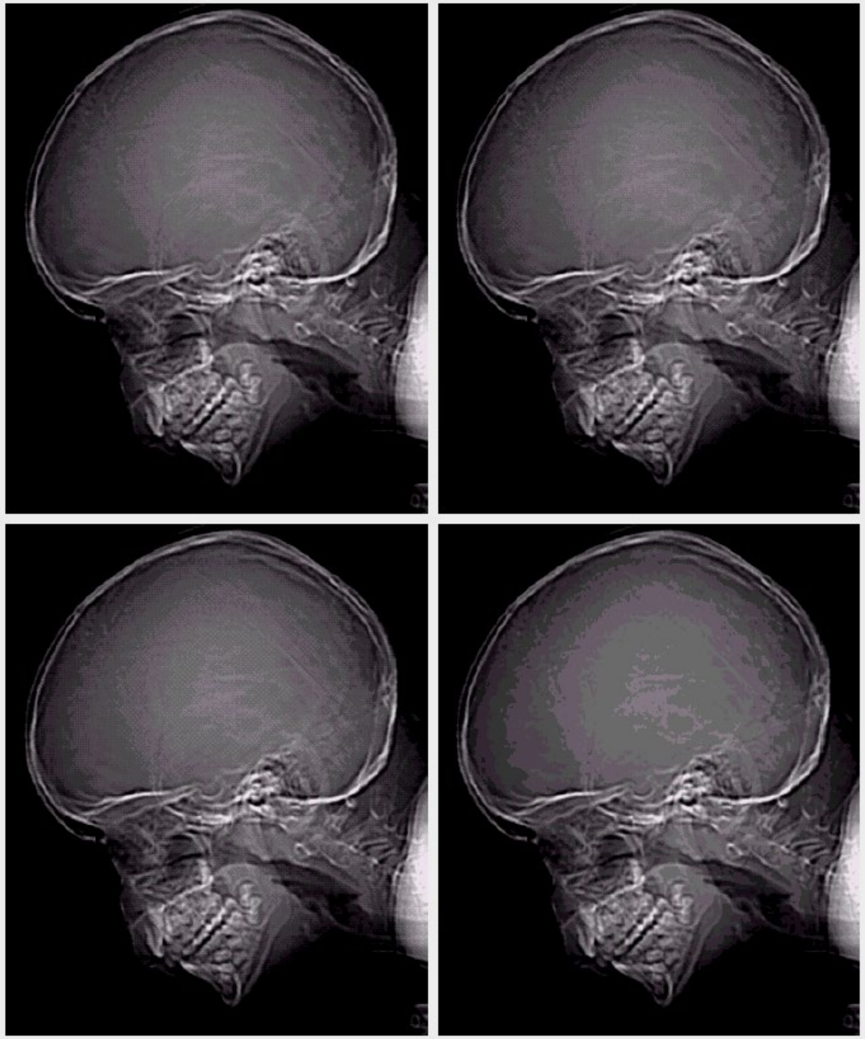
- Sampling theorem (2-D case, spatial domain). A bandlimited analog signal, which has been sampled, can be perfectly reconstructed from an infinite sequence of samples if the sampling rate exceeds $2N$ samples per unit distance, where N is the highest frequency in the original signal. If a signal contains a component at exactly frequency N, then samples spaced at exactly $1/(2N)$ per unit distance do not completely determine the signal.
- Corollary: If an image is scanned at a rate $d_{\text{scan}} > 2N$, where N is the highest frequency in the image, its spatial resolution is adequate, otherwise some of its details should me lost and distorted due to aliasing (to be considered later).

Spatial Resolution

a b
c d

FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

Intensity Resolution



a b
c d

FIGURE 2.21
(a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

Intensity Resolution

e f
g h

FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)